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ABSTRACT

The purpose of this study was to examine the kinematics, kinetics, and timing of muscle activation of the hamstring and gluteal muscle groups during drop jump landings after five minutes of visual and verbal landing strategy intervention. Thirty-six university students (23.47 ± 2.77 years; 171.99 ± 8.01 cm; 71.72 ± 13.56 kg) volunteered to participate. A 5-minute verbal and visual feedback intervention was implemented after participants performed five drop jumps. After the 5-minute intervention, five more drop jumps were performed. The results revealed significant differences in hip and knee flexion, knee valgus, and ground reaction forces pre and post intervention [$p<0.05$]. In addition, muscle-firing patterns revealed the hamstrings and gluteal muscle groups achieving 20% MVIC prior to the quadriceps muscle group post intervention. The current findings revealed that a 5-minute verbal and visual intervention can elicit greater hip and knee flexion, decrease ground reaction force, and increase the activation of the hamstrings while decreasing the activation of the quadriceps, thereby lessening the likelihood of an ACL injury.

INTRODUCTION

One of the most common sports injuries in female athletics is an anterior cruciate ligament (ACL) tear.[1] Every year about 100,000 ACL injuries occur in the United States, with a suspected growth to 200,000 in 2011.[2,3] Of those, 70% were noncontact.[2] Annually in the United States, 60,000 to 70,000 ACL reconstructive surgeries are performed.[3] With the amount of ACL injuries increasing each year, research has focused on ACL injury prevention. Recently, research has focused on determining the effectiveness of plyometric neuromuscular training as a form of injury prevention.[1]

The original use of plyometric training was for sports requiring explosiveness, power, and increased vertical jump height.[4-6] In addition, plyometric training has also led to performance gains.[5,7] Because of the amount of muscle activation recorded during plyometric training, many are in support of utilizing plyometric training as an adjunct not only to strength training, but also injury prevention.[8-11]

Female athletes participating in sports that involve cutting, pivoting, or jumping are more at risk of sustaining ACL injuries.[1,12] Research has shown that females typically utilize their quadriceps as a compensatory mechanism for inefficient antagonist muscles.[1,12] Research has demonstrated that increased gluteal and hamstring activation coupled with decreased quadriceps activation has the propensity to decrease knee injuries.[12] The gluteus maximus is activated during vertical movements and acts as a primary extensor of the hip during vertical jumps, while the gluteus medius is a primary abductor.[12] When knee injuries are of concern, the ability to produce hip abduction is fundamental.[12] The use of the hamstring muscles upon landing allows for greater force dissipation.[13] Hamstring activation results in the individual landing with greater knee flexion as opposed to knee extension.[1,12] Plyometric training largely focuses on increasing the strength and power of the gluteals and the hamstrings in an attempt to dissipate landing forces.

Plyometric training affords a controlled environment for female athletes to improve their hamstring and gluteal strength while focusing on greater hip and knee flexion. If the hamstrings and gluteals are strong and efficiently utilized during jump landings, the individual will land with greater hip and knee flexion.[12] Greater hip and knee flexion during jump landings have been linked to a decrease in ACL injuries in female athletes, as well as improvements in lower-extremity biomechanics.[1]

Consequently if proper utilization of the hamstring and gluteal muscle groups are observed during plyometric exercise, it is probable that neuromuscular training can indeed improve muscle activation and landing mechanics. It is a known fact that neuromuscular training of the lower extremities should be incorporated into athletic training regimens in sports that call for a large amount of cutting and fast deceleration.[1,12] Therefore, it is the purpose of this proposed study to examine the kinematics, kinetics, and timing of muscle activation of the hamstring and gluteal muscle groups during drop jump landings after 5-minutes of visual and verbal feedback of proper landing techniques.

METHODS

Thirty-six university students (23.47 ± 2.77 years; 171.99 ± 8.01 cm; 71.72 ± 13.56 kg) volunteered to participate. The participants were active collegiate coeds from the University of Arkansas. Active was defined as participating in thirty minutes of moderate-intensity physical activity at least five days a week. Participants reported for testing prior to engaging in any resistance training or any vigorous activity that day. Data collection with the participants took place at varying times throughout the day starting in the morning and ending in the early afternoon. University of Arkansas Institutional Review Board approved all testing protocols, and prior to participation the approved procedures, risks, and benefits were explained to all participants. Informed consent was obtained and the rights of the participants were protected according to the guidelines of the university's Institutional Review Board.

Kinematic data were collected via the MotionMonitor™ (Innovative Sports Training, Chicago, IL) motion analysis system via an electromagnetic tracking system (Flock of Birds Ascension Technologies Inc., Burlington, VT). Kinematic data were collected to allow for event marking of the electromyographic (EMG) data collected via the Noraxon system. Participants had a series of eight electromagnetic sensors attached at the following locations: [1] the medial aspect of the torso at C7; [2] medial aspect of the pelvis at S1; [3-4] distal/posterior aspect of bilateral lower legs; [5-6] distal/posterior aspect of bilateral upper legs; [7-8] bilateral aspect of the fore foot.[14] Sensors were affixed to the skin using double sided tape, with the sensor cord pointed upwards, and then wrapped using flexible hypoallergenic athletic tape to ensure proper placement throughout testing. Following the attachment of the electromagnetic sensors, a 9th sensor was attached to a wooden stylus and used to digitize the palpated position of the bony landmarks.[1,15-17] Participants were instructed to stand in anatomical neutral while selected body landmarks were accurately digitized. Joint centers for the ankle, knee, hip, shoulder, T12-L1, and C7-T1 were determined from previously established protocols[18] and a link segment model was developed through digitization of joint centers for the ankle, knee, hip, shoulder, T12-L1, and C7-T1.

Surface EMG data were transmitted through a Noraxon Myopac (Noraxon Inc., Scottsdale, AZ) 1400L 8-channel amplifier and sampled at a frequency of 1000 Hz. Location of dominant-side gluteus maximus, gluteus medius, hamstring and quadriceps were identified through palpation. Adhesive 3M Red-Dot bipolar surface electrodes (3M, St. Paul, MN) were attached over the muscle bellies and positioned parallel to muscle fibers.[19] Once all electrodes had been secured, manual muscle tests (MMT) were conducted for each muscle in an attempt to identify maximum voluntary isometric contraction (MVIC) for each muscle.[20] Each MMT was conducted to establish baseline readings for each participant's maximum muscle activity to which all sEMG data could be compared.

After all sensors and electrodes were positioned the participants were explained the drop jump protocol. Participants dropped off a 47cm box, and upon landing, performed a vertical jump, landing again in a squatting position. Participants landed on a Bertec (Bertec Corp, Columbus, Ohio) force plate 40cm by 60cm that recorded the vertical ground reaction force synched through the MotionMonitor™. Each participant performed five-drop jumps. Immediately following the drop jumps, participants were given an intervention that included visual and verbal feedback of landing techniques. The verbal feedback statements are summarized in Table 1.[21,22] Visual feedback was provided using the Noraxon EMG system containing bar graphs of each muscle's activity as a means of biofeedback. Each participant watched the EMG screen as they jumped and observed the bar graphs increase or decrease for the muscle activation in the gluteals, hamstrings, and quadriceps depending on the participant's change in form. The participants were instructed to try and get their quadriceps activation bar to decrease and the gluteal and hamstring bars to increase as they landed. Following 5-minutes of the visual and verbal feedback intervention, the participants performed five more drop jumps. The period from foot contact to maximum knee flexion was chosen for analysis.

Please insert Table 1 here.

RESULTS

Paired sample t-tests were performed to determine kinematic and kinetic differences pre and post intervention. Paired t-test revealed significant differences between all kinematic and kinetic variables [$p < 0.05$] pre and post intervention (Figures 1-4). The sequence of muscles firing upon foot contact to maximum knee flexion was categorized by the order each muscle achieved 20% MVIC during the landing task. The 20% MVIC was used, because a smaller window of time was needed in order to focus closely on the timing sequence of the gluteus maximus, gluteus medius, biceps femoris, and rectus femoris. Timing results taken from the electromyographic system (EMG) are presented in Figures 5 and 6.

Please insert Figures 1-6 here.

DISCUSSION

The study revealed that a 5-minute intervention consisting of verbal and visual landing techniques resulted in increased knee and hip flexion as well as decreased knee valgus and ground reaction forces. From the five minutes of neuromuscular training intervention participants displayed efficient landing mechanics that have been reported to decrease injury susceptibility.[13,14] In addition, based on the kinematic alterations in hip and knee flexion, the muscle activations also displayed greater gluteal and hamstring activation as compared to quadriceps activation. The increased hip and knee flexion, and decrease in knee valgus and ground reaction force are ideal injury prevention mechanics.[13,14] An increase in hip and knee flexion during landing allows the body to better absorb joint forces, thereby increasing joint stability.[13] Also, increased knee flexion has been reported to increase hamstring activation, providing protection to the ACL. If there is greater hip and knee flexion, less peak anterior shear forces will be experienced.[22,23]

In addition to the increase in knee and hip flexion, a significant decrease in ground reaction forces were also reported. The ground reaction force is what helps to cause flexion in both the knee and hip and is related to how much compressive force is placed on the joint.[23] If the athlete lands with a more extended knee, the ground reaction force loads the tibia in all planes, which places compressive forces on the joint, and creates a higher risk for injury to the ACL.[23] If the athlete flexes the knee and hip, she will land more lightly, placing less force on the joints.[13] Initiating both knee and hip flexion, insure that the tibia and femur glide on one another, acting as a protective mechanism for the knee.[23] Therefore in agreement with the theory of landing with greater knee and hip flexion in an attempt to decrease ground reaction forces, the same was revealed with the intervention utilized in this study.

Besides addressing the kinematics and kinetics of landing techniques, muscle activation allows for an enhanced description of the landing mechanics. It has previously been reported that females are typically quadriceps dominant when performing landing tasks.[13] A quadriceps dominant mechanism of landing is evident in the appearance of a more extended knee. When one lands with her knee more extended, then there is decreased hamstring activation as evident by the lack of knee flexion. When the quadriceps fire before the hamstrings and gluteals, there is an increase in ACL strain.[13, 24] Additionally, if one lands and cuts with greater quadriceps activation then one is at greater risk of ACL injury due to anterior displacement of the tibia in relation to the femur.[13,24] Thus focus is on the ability of neuromuscular training to decrease quadriceps dependence and activation in jump landing, cutting, and pivoting activities. As the current data revealed, participants whose gluteus medius fired first, gluteus maximus second, and biceps femoris third during the post intervention increased when compared to pre-intervention. During post intervention, more participants were able to decrease their rectus femoris activity, with it being the fourth muscle group to fire. The results revealed a decrease in quadriceps dependence and activation of the hamstrings and gluteals prior to that of the quadriceps. Use of the hamstrings and gluteals before the quadriceps in landing technique provides protection for the ACL, and consequently a decrease in the risk of ACL injury.[21-24]

CLINICAL IMPLICATIONS

This study revealed that athletes who participate in sports that involve cutting, pivoting, and jumping could possibly benefit from a training program that involves teaching correct techniques for jumping and landing. If training programs can be created to increase hip and knee flexion and increase hamstring and gluteal activation while decreasing quadriceps dependence, the amount of ground reaction force on the knee would decrease thereby decreasing the probability of non-contact related ACL injuries in sports. Further research is needed to determine the ideal duration and frequency of jump training programs and their effectiveness on prevention of ACL injury. These current results can be implemented in the field by encouraging sports teams to implement training programs in which a strength and conditioning coach verbally coaches the athletes on correct form. Further research needs to be done to determine if verbal feedback alone would be sufficient in allowing for more efficient landing mechanics.

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Table 1. Intervention instructions to the participants**.**

- Position to land on the balls of your feet with knees bent
- Upon landing, lower heels slowly to ground and bend at knees
- Try to land as soft as possible
- Focus on tightening your hamstrings and gluteals

Figure Legends:

Figure 1. Hip flexion mean and standard deviation pre and post intervention.

Figure 2. Knee flexion mean and standard deviation pre and post intervention.

Figure 3. Knee valgus mean and standard deviation pre and post intervention.

Figure 4. Vertical ground reaction force mean and standard deviation pre and post intervention.

Figure 5. Vertical axis represents the number of participants who achieved 20% MVIC and the horizontal axis represents the order of muscles achieving 20% MVIC during pre-testing.

Figure 6. Vertical axis represents the number of participants who achieved 20% MVIC and the horizontal axis represents the order of muscles achieving 20% MVIC during post-testing.

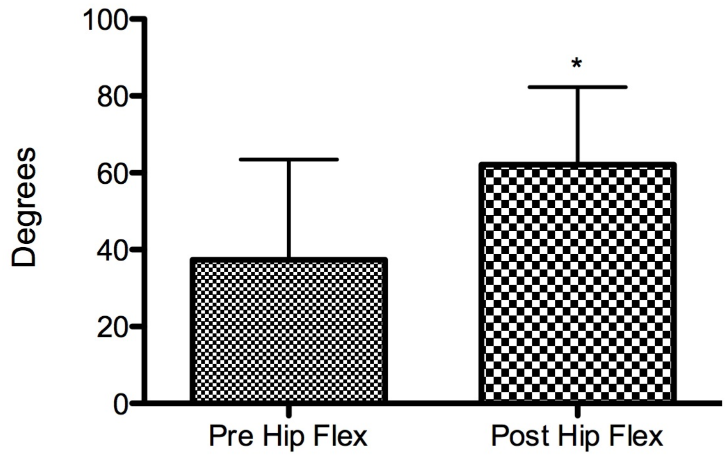

Figure 1. Hip flexion mean and standard deviation pre and post intervention.
* = significant difference; t(35) = 5.99, 0.0001; R squared 0.51

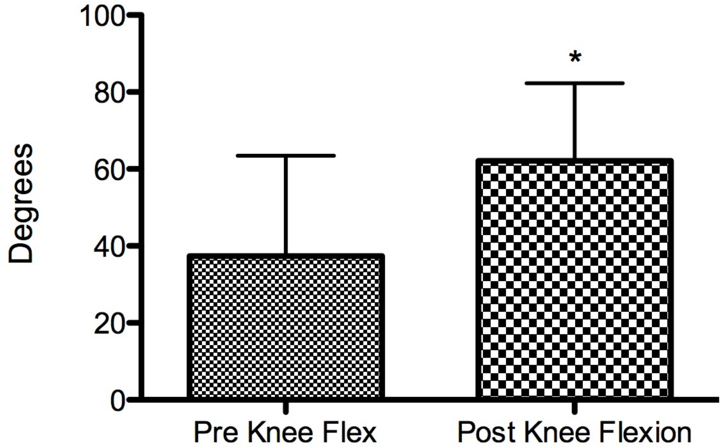

Figure 2. Knee flexion mean and standard deviation pre and post intervention.
* = significant difference; t(35) = 7.7, 0.0001; R squared 0.63

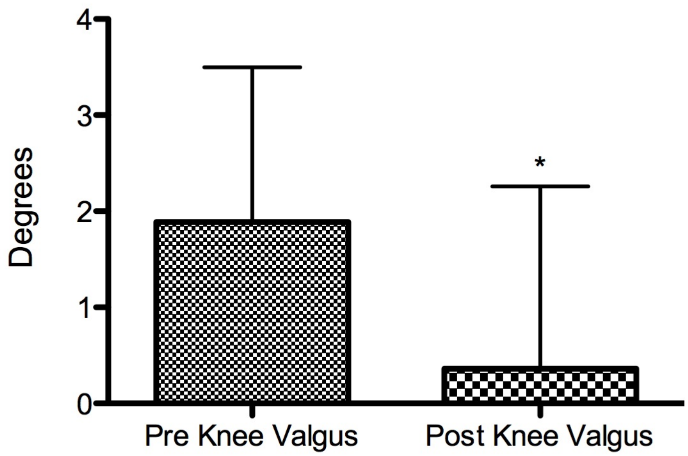

Figure 3. Knee valgus mean and standard deviation pre and post intervention.
* = significant difference; t(35)= 0.77, 0.44; R squared 0.02

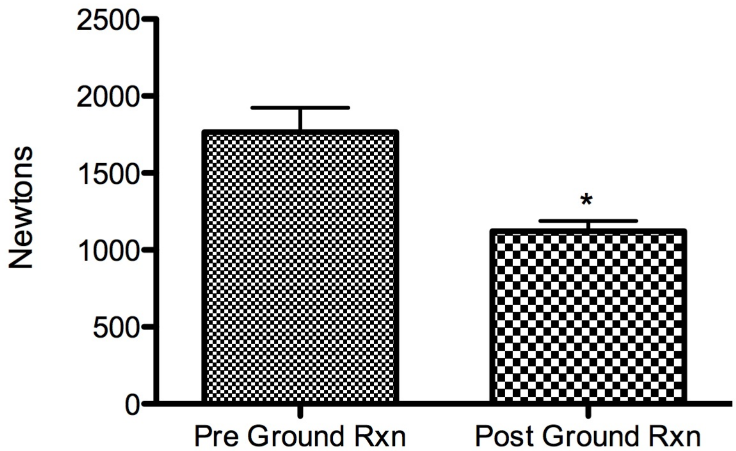

Figure 4. Vertical ground reaction force mean and standard deviation pre and post intervention.
* = significant difference; t(35)=4.4, 0.008; R squared 0.35

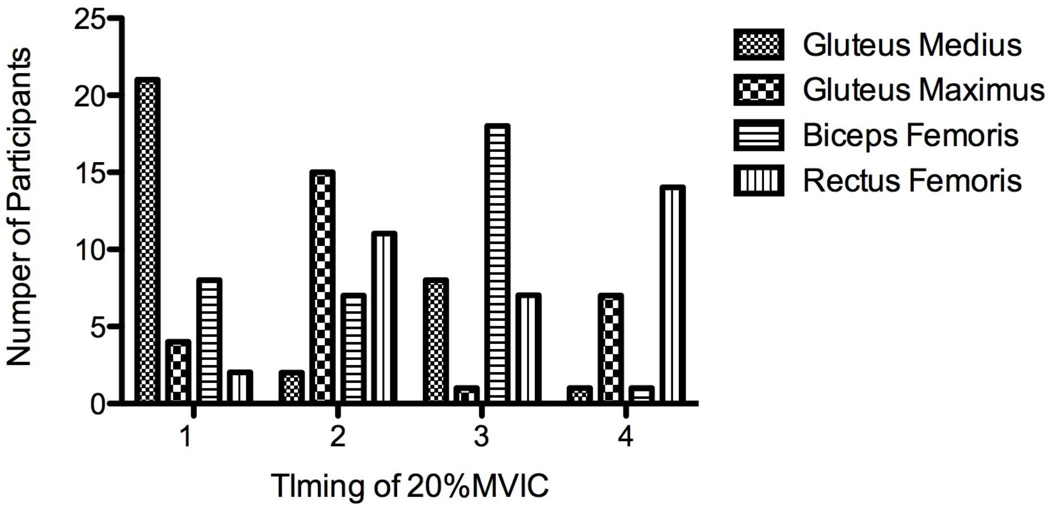

Figure 5. Vertical axis represents the number of participants who achieved 20% MVIC and the horizontal axis represents the order of muscles achieving 20% MVIC during pre-testing.

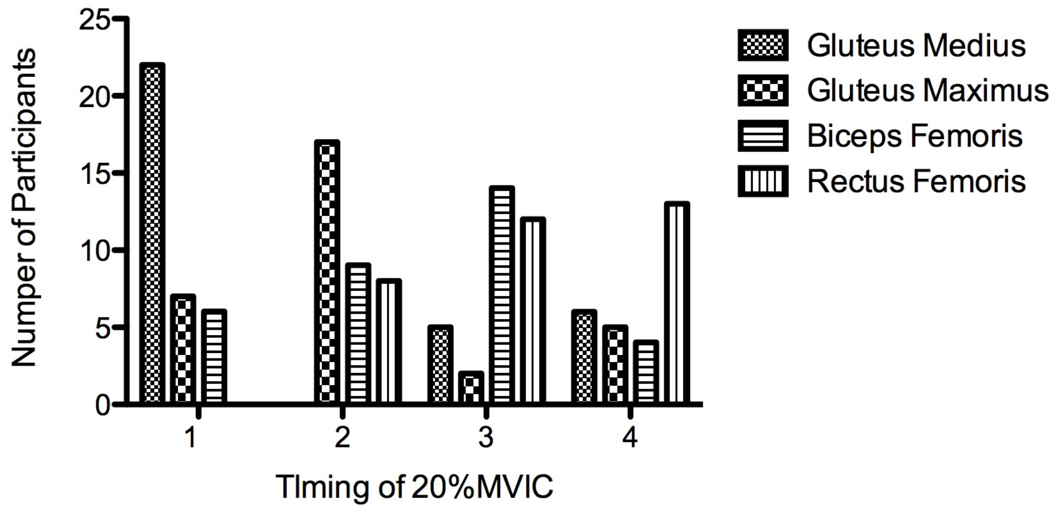

Figure 6. Vertical axis represents the number of participants who achieved 20% MVIC and the horizontal axis represents the order of muscles achieving 20% MVIC during post-testing.